METHOD AND SYSTEM IN A DIGITAL IMAGE PROCESSING CHAIN FOR ADJUSTING A COLOUR BALANCE, CORRESPONDING EQUIPMENT, AND SOFTWARE MEANS FOR IMPLEMENTING THE METHOD

5   The present invention relates to a method in a digital image processing chain for adjusting a colour balance, in which method

- the subject is imaged by pixels to form value-sets of the colour components,

10   - component-specific histograms are formed from the value-sets of the colour components,

- cumulative histograms are formed from the component-specific histograms,

- the illumination colour corresponding to at least
15   one colour component is defined from the cumulative histograms,

- using target colour and defined illumination colour are defined for at least two colour components, a gain factor adjusting the colour balance.

20 In addition, the invention also relates to a corresponding system, equipment, and software means for implementing the method.

As is known, the human visual system is able to adapt to dif-
25 ferent illumination colours. Objects in the field of vision appear to have unvarying colours within the range of variation of the illumination colour. An example of such a situation is one in which white objects are recognized as being white, in both sunlight and also in brilliant white illumination, de-
30 spite the more bluish hue of sunlight. Once the illumination colour leaves the range of human adaptation, the degree of adaptation is reduced, but nevertheless some change in the colour is sensed. For instance, white objects then appear to be somewhat yellow when seen during sunset.

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The mechanisms and operation of adaptation in the human visual system are still not fully known and understood. Adaptation takes place partly in the retina, in which the colour receptors' sensitivities change uniformly during a specific period,

5   according to their stimulation. It is also known that other parts of the adaptation mechanisms are controlled by the cerebral cortex, in which the processes taking place are extremely complex.

10   Part of the adaptation processes appear to use so-called memory colours, when evaluating the correct colour balance. Examples of memory colours are colours like white, skin colour, grass, the sky, and generally other colours that have a specific primariness in specific instances.

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The sensors used in digital cameras are not able to automatically provide an adaptability similar to that of the human visual system (nor even a functionality corresponding to the retina). The sensor determines the amount and colour of the

20   light being reflected from the imaging object, but in no way the visual sensation related to it. Thus, images that have been taken, and to which no adjustments have been made, appear to have a distorted colour balance. This is because, when a person is viewing an object, their visual system adapts to the

25   illumination of the environment, instead to the content of the image. White objects may appear to be blue or yellow, depending on whether the image is taken indoors or outdoors. Naturally, other colours too may appear, depending on the illumination.

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Due to the above among other factors, some kind of colour-balance adjustment is made in digital camera equipment and in image-processing chains in general. The adjustment is very often termed automatic white balance, or simply white balance,

35   if the adjustment is performed manually. The aim is to adjust

the colour balance so that the image will look natural in neu-
tral viewing conditions.

The problem concerning achieving a proper colour balance is,
5   however, very difficult. The operation of the human visual
system is extremely complex, and so far it has proved impossi-
ble to fully analyse and understand it. However, in general,
the problem can be divided into two parts. These are 1) the
estimation of the illumination colour while taking an image
10   and 2) the definition of the type of correction required by it
and the calculation and adaptation of an appropriate amount of
correction to the taken image.

Automatic systems perform these tasks without requiring any
15   actions by the user of the camera equipment. In manually per-
formed illumination-colour adjustment methods, the illumina-
tion colour is set by an action of the user of the camera. The
camera may have predefined settings, such as indoor and out-
door imaging modes, or colour-temperature adjustment. The user
20   may also aim the camera at a known colour, which is typically
white, and from which the camera then defines a correction,
based on this selected reference colour.

A large number of solutions to the problems described above
25   are disclosed in the prior art, because colour-balance adjust-
ment is absolutely essential in digital imaging equipment. The
adjustment can be implemented, either in the camera, or else
as post-processing of a taken image, in some other device (for
example, in an image-processing program in a PC).
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From the user's point of view, perhaps the most satisfactory
solution to the problem is to arrange an automatic colour-
balance adjustment function in the camera, which is imple-
mented in connection with the taking of the image. In such a
35   solution, the user is not required to have any particular

knowledge of image processing, or even generally of the control of the camera's adjustment buttons.

As is known, there are at least three basic types of adjustment for the illumination colour, which are based on using illumination-colour estimation algorithms.

Grey-world algorithms are one of the first of these algorithms. These are based on simple emulation of the adaptation ability of vision. In a simplified form, the average colour of the image is calculated in them. This assumes that the colour should be neutral, in other words, grey. The colour components of the image are then adjusted so that its average colour moves towards this grey. The aim is to control the amount of the adjustment in such a way as to take into account more or less the entire adaptability of human vision. Grey-world algorithms are very widely used as a basis for colour-balance adjustment algorithms in digital camera devices.

A second such adjustment algorithm is known as brightest white balance. As is known, a pure white surface will reflect the entire spectrum of illumination. Thus, the colour of white areas will also tell the illumination colour. When fully adapted, the white areas should remain white, so that the illumination colour can be directly compensated. The brightest areas of images are usually white surfaces, so that brightness can be used to search for white areas.

Colour saturation and hue can also be taken into account. These properties can also be used to determine the amount and type of colour-balance correction, in such a way that the adaptability of vision can be more or less taken into account. Due to the dominant importance of the white colour, the entire group of colour-balance algorithms are often called white-

balance algorithms, even if they do not even measure the illu-
mination colour from white, or balance the white colour.

Algorithms based on a maximum colour can be given as a third
5 example. If the image has even one surface that perfectly re-
flects some part of the illumination spectrum, this part of
the spectrum will then be known. If a perfectly reflecting
surface exists for each part, the entire spectrum can be re-
constructed. Typically, camera sensors do not measure the
10 whole spectrum, but only some of its sub-bands, or colour
channels. Thus, if the image contains combinations of sur-
faces, which perfectly reflect the parts of the illumination
and so affect these colour channels, the effect of the illumi-
nation on the appearance of the image can be estimated.
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Most digital cameras, though not, however, all, use three col-
our channels to record the colours of the view. These are
typically red, green, and blue (RGB). To simplify slightly,
this means that, if the image includes surfaces that perfectly
20 reflect the illumination colour's red, green, and blue compo-
nents, the illumination colour can be estimated from them.

Typically, the maximum value of each colour component is re-
lated to perfect reflection. With this assumption, it can be
25 concluded that the maximum values of the colour components
also determine the illumination colour. It should be noted,
that quite often these values are reflected from the brightest
white surface. In that case, the use of the method based on
maximum colours will be close to the brightest-white algo-
30 rithms. However, the presence of white is in no way essential
when using the maximum-colour method. The most suitable colour
spaces for the implementation are also different. Like other
methods, methods based on maximum colour may adjust the amount
and type of correction, based on the estimated illumination.
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In addition, the methods described above can also be combined. Some methods may thus belong to more than one of the above groups. The colour balance can be made more robust by using several methods simultaneously and combining their results

5   sensibly.

In camera-device-specific image-processing chains, the colour-balance algorithms must operate in co-operation with the other image-processing algorithms. The chain can be implemented in

10   the actual camera device, or also as post-processing functions in some other device. Typical algorithms of the chain concern not only colour-balance adjustment, but also colour-filter-array interpolation (CFAI), digital gain control, black-level adjustment, noise reduction, vignetting correction, geometri-

15   cal-distortion correction, image enhancements, such as sharpening and gamma correction, or some other kind of sensor-response correction.

The implementation of the chain can also be divided into func-

20   tions to be performed in the camera and functions to be performed as post-processing. In addition, they can be implemented as both hardware and software solutions. The implementation can be completely separate from the implementations of other algorithms, so that they can take as input for analysis

25   and processing only the image data from a previous algorithm, with no other information relating, for example, to the previous algorithm.

On the other hand, the algorithms may also co-operate very

30   closely with each other. A typical example of this is an arrangement, in which the colour-balance algorithm can control gains in the colour components. The implementation of the solutions can both analog and digital. All in all, it would be extremely advantageous, if the colour-balance adjustment algo-

rithm could be implemented as effectively and naturally in a camera-specific image-processing chain.

The main weakness in solutions according to the prior art is ineffective or erroneous operation. Their effect varies with the algorithm. A general problem with all methods (for example, in shots taken during sunset) is achieving a compromise between effectively operating colour-balance adjustment and the loss of the colour appearance of the view. In addition to this, each group of algorithms has its own typical cases of errors.

Grey-world algorithms adjust the colour content of the image in such a way that the average effect of the image becomes neutral. Their main problem is that neutral images are only optimal in some special cases. The cases are those in which there should be an equal number of all colours after balancing. An example of an opposite case to this is a portrait shot, in which the average colour should clearly be moved towards skin colours. This method is also extremely sensitive to large areas of colour in the image. These distort the colour balance towards the complementary colours of the subject. Several modifications have been used to increase the robustness of these algorithms. For example, the weighted averages of hue, saturation, or spatial distribution can be used to reduce the effect of highly saturated colours and large areas of colour. Similar problems nevertheless remain, unless the effect of the colour balancing is limited. In this case, many images, which would require balancing, will remain uncorrected.

Brightest-white-balance algorithms are extremely sensitive to saturation of the pixel values. If the dynamic area of the camera sensor is exceeded, the pixel values will be limited to the maximum value. A brightest-white-balance algorithm is extremely suitable for use with colour spaces that define the

brightness signal. However, the sensor typically defines the colour from the RGB channels. Saturation will therefore also appear in the RGB domain. If all components are saturated, the brightest-white-balance method will erroneously estimate the illumination colour as white and as a result balancing will not be performed. If one or two components are saturated, an erroneous estimate will be found for some other illumination colour. These methods also require a white surface to be found in the image. Otherwise, the method will fail to estimate the illumination colour.

Methods based on maximum colour are also sensitive to saturation of the pixel values. Usually, these methods select some number of the brightest values, which define the illumination colour. Therefore slight saturation is permitted. In some cases, however, this causes problems. The algorithm also demands that perfectly reflecting surfaces must be found in the imaging object for all the colour components. As this condition is not met, for example, in the case of nature images, these methods too fail at times.

Problems have also been known to appear in functions that relate quite substantially to the success of colour-balance adjustment, or at least in their compatibility with it. One example of these functions is the need for biassing and vignetting elimination, caused by inferiority properties in the sensor. In many cases, it would be practically essential to bias the sensor in some way, as otherwise the sensor would produce a signal, even though what it detects is completely black. The need for vignetting elimination also usually arises from the sensor's 'inferiority', in which case darkening may appear in the edge areas.

As a prior art referring to the patent publications can be mentioned US-publications US-2003/0174216 A1 and US-2002/0024609 A1.

5   The present invention is intended to create a new type of method and system for adjusting colour balance in a digital image processing chain. The characteristic features of the method according to the invention are stated in the accompanying Claim 1 and those of the system in Claim 15. In addition,
10   the invention also relates to corresponding equipment, the characteristic features of which are stated in Claim 20 and to software means for implementing the method, the characteristic features of which are stated in Claim 21.

15   In principle, in the method according to the invention, the object is imaged initially as pixels to form a value-set of the colour components (R, G, B), from which, according to one embodiment, at least all such individual pixel values, or image areas formed of several pixel values, in which one or more
20   pixel values in even one value-set exceed/meet a selected criterion, are filtered out of each value-set, according to the method of the invention. Thus, for example, distortions caused by saturated pixels can be eliminated, when estimating the illumination colour.

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Cumulative histograms of the colour components, from the colour curves of which an illumination colour (R_{ill}, G_{ill}, B_{ill}) corresponding to each colour component is defined, are then formed from the filtered value-sets.

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In the method according to the invention, the illumination colour is defined from the flat area of the colour curve at the end of each filtered cumulative histogram. A common point h_i, in the which the ratio C_i / C_{i+1} (or the difference) be-
35   tween the consecutive pixel-intensity values meets a criterion

set for it, is sought from the flat area for at least one col-
our component. In a cumulative histogram, the interval of the
points h_i, which is thus the same for each colour component,
can be set to be quite suitable, because, among other things,

5   the saturated pixels are filtered out in a previous stage of
the method. The illumination colours thus defined are then
used to form componentwise mappings that adjust the colour
balance. As such, the illumination color can be compensate by
using any known method. The invention mainly relates to this

10   definition of the illumination colour. In one embodiment, the
flat area is recognized using two colour components and at
least one colour component is adjusted.

The use of the method according to the invention permits the
15   robust and effective control and type definition of the col-
our-balance correction gain. In addition, it achieves good re-
sults in difficult lighting conditions too.

The colour-balance adjustment method according to the inven-
20   tion can be very effectively implemented in camera-specific
imaging chains. It can be made to operate naturally in co-
operation with other algorithms. The degree of complexity of
the method, which remains reasonable, makes it applicable to
camera devices, for instance. However, the method can also be

25   applied, for example, to post-processing taking place outside
a camera device.

According to one embodiment, three sub-criteria are used to
define the illumination colour in the method according to the
30   invention. In them, the pixel (intensity) value relations cor-
responding to consecutive cumulativity distributions are com-
pared in a set manner to the criterion values set for them.
The criterion values can be based, for example, on experien-
tial data that have been shown to give good results in colour-
35   balance adjustment.

According to another embodiment, prior to colour-balance ad-
justment according to the invention, pedestal elimination, for
example, can also be performed on the raw-matrix pixel values.
5   This will significantly reduce the unnecessary signals pro-
duced by the sensor.

Yet other functionalities that can be integrated in the method
according to the invention include vignetting elimination,
10   dark-colour correction, and gamma correction.

The method according to the invention can even be implemented
in a fully automated manner in a camera device, but also, how-
ever, as post-processing. In addition, the user's own discre-
15   tion can easily be connected to the method.

The method and system according to the invention can be quite
easily integrated in both existing image-processing chains and
camera devices, as well as in those presently being designed.
20   The method according to the invention scarcely adds so much
complexity to a camera device that it would cause a noticeable
detriment to, for instance, the processing power of the equip-
ment or its memory use. According to one embodiment, even the
method implemented on a purely software level can be inte-
25   grated extremely easily in, for example, camera devices.
Purely hardware-level implementations and combinations of
hardware/software level implementations are naturally possi-
ble. The method may be implement either automatic or half-
automatic.
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Other characteristic features of the method, system, equip-
ment, and software means according to the invention will be
apparent from the accompanying Claims while additional advan-
tages that can be achieved are itemized in the description
35   portion.

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In the following, the method, system, equipment, and software means for implementing the method, according to the invention, which are not restricted to the embodiments described in the
5   following, are described in greater detail with reference to the accompanying drawings, in which

Figure 1   shows a schematic diagram of one example of an image-processing chain according to the
10   invention,

Figure 2   shows one example of colour-component pixels in a sensor,

Figures 3a and 3b   show a comparison between the prior art and the method according to the invention, when
15   forming componentwise histograms from them,

Figures 4a and 4c   show componentwise cumulative histograms as schematic embodiments in connection with the method according to the invention,

Figure 5   shows a schematic diagram of the principle
20   of offset correction,

Figure 6   shows a schematic diagram of the principle of dark-colour correction,

Figure 7   shows the processing of histograms, according to the method of the invention,

25   Figure 8   shows examples of gamma-correction curves as examples in principle, and

Figure 9   shows tabled examples of the criterion values used in the colour-balance adjustment method according to the invention.

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The schematic diagram in Figure 1 shows one example of a digital image processing chain 10 according to the invention. Such an image processing chain 10 can be arranged, for example, in a digital camera device, or in general in a device equipped
35   with a camera sensor, which can be found nowadays, for in-

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stance, even in mobile stations. The colour-balance correction method according to the invention is very suitable for numerous different camera-specific imaging chains, the implementation of which can naturally differ from that shown in Figure 5   1. In addition, the chain 10 can naturally also be applied to post-processing, for example, implemented with software means (e.g., in connection with image-processing software).

Co-operation between the colour-balance adjustment method and 10 other functions arranged in the image-processing chain 10 can also be quite easily implemented effectively. In this case, the method according to the invention is shown in an image-processing chain 10, which includes CFAI, vignetting elimination VE, sensor pedestal elimination PE, and gamma correc- 15 tion/estimation GE, GA. Any point at all of the chain 10 can naturally also include other signal-processing functions, one example of which is colour gamut conversion CGC (not shown), arranged before gamma correction.

20 The actual colour-balance adjustment method according to the invention includes several sub-stages, such as the illumination colour estimation stage CBA, and correction stage CBC. Figure 1 shows how the colour-balance adjustment stages CBA, CBC relate to the other functions in the imaging chain 10. In 25 Figure 10, the cross-hatched blocks CBA, CBC are the core components of the method. The hatched blocks PE, GE, GC can operate in close co-operation with the method according to the invention. The unhatched blocks VE and CFAI can be independent, but also relate to the colour-balance adjustment.
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Next, the method and system according to the invention are described in an image-processing chain 10 according to the invention, of a kind that can be, for example, in camera equipment according to the invention, as an individual example of

an application, starting from the functions CBA, CBC relating
to colour-balance adjustment.

The first stage of the actual colour-balance adjustment is the
estimation of the illumination colour R_{ill}, G_{ill}, B_{ill}. In the
method according to the invention, the estimation is performed
on the basis of the colour-component histograms of the image.
Componentwise colour curves are then formed from the main col-
ours R, G, B.

The brightness/darkness (intensity) of the pixels are depicted
on the X-axis of the histograms, so that, for example, the
right-hand end of the X-axis is the bright end and the left-
hand end the dark end. Similarly, the Y-axis is used to depict
the number of pixels corresponding to each brightness level.
The formation of the histogram represents a technique that is,
as such, known, and is therefore not described at greater
length in this connection. The histograms of the signal values
(i.e. intensity values) of each colour component (R, G, B) are
measured separately from each other.

The componentwise histograms can be gathered either from the
interpolated signals, or also before the interpolation of the
signals, which is used in this implementation example. This
means that the colour-component histograms can be defined from
raw image data, in which each physical pixel of the camera
sensor represents only one colour component. Though in this
case the sensor's colour system is described at the RGB level,
other techniques too (CMYK, YUV, etc.) will be obvious to one
versed in the art.

A typical implementation for performing such an operation is,
for example, the well-known Bayer-matrix arrangement, shown in
Figure 2. More generally, this means the depiction of the sub-
ject by pixels to form value-sets [R], [G], [B] of the colour

components R, G, B. In the case of the RGB application example
described in the application, two pixels out of four are green
while one pixel is red and one is blue. There are more green
pixels, because green best depicts the luminance and is thus
5   important from the point of view of the eye. However, such a
sensor is also possible, in which, for example, only every
fifth pixel represents the colour green G. Sensors are typi-
cally more sensitive to green than to red or blue.

10   The histograms are collected by scanning through the pixels of
the image. The number of incidences of each possible signal
level is calculated for each colour component R, G, B. Thus,
for example in the case of an RGB image, three histograms are
obtained, which are shown in Figure 3a.
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However, a important drawback can be seen in the case shown in
Figure 3a, which relates generally to the prior art in illumi-
nation-colour estimation. This problem is caused by the detri-
mental effect of possible saturated pixels, even a single
20   saturated pixel $G_{(s)}$ in an image point 15.1 - 15.3 of each shot
being sufficient to disturb the other pixels R, G, B of the
image subject. In the histogram 3a, this means a large number
of pixels with the highest signal value. This leads to prob-
lems that were described in greater detail earlier in the ap-
25   plication. This appears as peaks in the histograms visible in
each colour curve R, G, B, (in Figure 3a).

In the method according to the invention, in the histogram's
collection stage, not only are these saturated pixels $G_{(s)}$ sur-
30   prisingly rejected, but so are the corresponding pixels R, G,
B of the image point 15.1. Figure 3b shows the effect of such
a procedural stage on the histograms in the method according
to the invention. This operation removes the high peaks of the
histograms, which would otherwise cause an error in the esti-

mation of the illumination colour appearing even in the prior art.

The filtering of the pixel values from each value set [R], [G], [B] is carried out before the cumulative histograms are formed. The filtering is directed at such pixel values $G_{(s)}$, or, in addition to them, to the pixels of such image points 15.1, in which even a single pixel value of the same image point 15.1, in even a single value-set [R], [G], [B] of the image point exceeds or meets the selected criterion set for it.

Estimation of the illumination colour according to the invention is not disturbed by the rejection of these saturated pixels $G_{(s)}$ and of other pixels R, G, B too over the same image point 15.1, - on the contrary the colour estimation is made more reliable. The limit point defining the saturation, i.e. the criterion value, can be set to make the method advantageously compatible with, for example, the pedestal-elimination stage to be described later in greater detail. The advantageous value depends on the general arrangement of the implementation. In example case, it is possible to use the criterion value that is obtained, if the factor pedestal value/2 is deducted from the maximum signal value, in which the pedestal value can be, for example, 64. The dark end can also be processed similarly.

Thus, if even one of the colour components R, G, B of the pixels of the same image point 15.1 is saturated ($G_{(s)}$), then the other component values R, G, B of the image point 15.1 are also rejected. In the case of a raw image, for which CFAI has not been carried out, this means that all the colour components R, G, B, belonging to the same raw-pixel group 15.1 are rejected. This and its effects on the collected histograms are illustrated on a schematic level in Figures 3a and 3b.

In Figures 3a and 3b, there are two raw-pixel groups 15.1 - 15.3, in one of which the saturation problem in question appears in a green pixel $G_{(s)}$. Peaks then form in the histogram
5   of Figure 3a, the formation of which takes into account all image points, i.e. raw-pixel groups 15.1 - 15.3. In Figure 3b, the raw-pixel group 15.1, which causes the problem, is rejected, so that the histogram curves R, G, B of the components become substantially less steep.
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In the following stage of the method, the illumination colour is estimated from the histograms formed from the filtered colour components. Figures 4a - 4c show the cumulative histograms of the colour components R, G, B, which are formed from the
15   actual histograms and from which the saturated pixels $G_{(s)}$ and their corresponding image points 15.1 have been filtered out as described above. According to one embodiment, the cumulative sum of pixel percentage proportions, or the number of pixels, or some other quantity corresponding to a num-
20   ber/proportion of pixels can be shown, for example, at predetermined selected intervals on the X-axis in the cumulative histograms, in which case the intensity values corresponding to them can be shown on the Y-axis. In an example case according to the embodiment, the pixels' cumulative percentage pro-
25   portions h_i, for example, set at predetermined intervals on the X-axis, state how great a proportion (or number) of the filtered pixels is before the intensity point R_i, G_i, B_i corresponding to them.

30   In the methods according to the prior art, the illumination colour is estimated from the points of the cumulative histograms, using a set colour representing a specific percentage proportion of pixels with values lower than the reference value.
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In the method according to the invention, the illumination colour is defined from an essentially flat area at the brightest end of the filtered cumulative histograms (the right-hand end of the colour curve in the histograms in Figures 4a - 4c).

5   In this flat area, or area that can be considered to be essentially flat (compared, for example, to the other areas of the curve), the curve of the histogram no longer substantially rises according to its set criterion conditions, i.e. the intensity value of the colour no longer substantially changes

10 according to the conditions set for it.

In one embodiment, an essential part is played by the procedure for searching for the flat areas of the colour curves, carried out from the cumulative histograms from which satura-

15 tion pixels $G_{(s)}$ and the their image points 15.1 have filtered out. After the setting of the predefined cumulative pixel-proportion points h_1, h_2, ..., h_n attached in a set manner and the intensity values ($R_1 - R_n$, $G_1 - G_n$, $B_1 - B_n$) corresponding to these points have calculated, according to the main princi-

20 ple of the method of the invention a search is made in the flat areas of the colour curves R, G, B for a common point h_i, defined at set intervals for each colour curve R, G, B, and at which the ratio C_i / C_{i+1} (C = R, G, B) of the pixel-intensity values corresponding to the consecutive points h_i, h_{i+1} defined

25 at set division intervals meets the criterion values set for it.

The illumination colour R_{ill}, G_{ill}, B_{ill} is defined by analysing the sequential intensity values C_i, C_{i+1} corresponding to these

30 points h_i, according to the method of the invention. It will be observed that, if the filtering stage of the saturation of the pixel values is bypassed, the method is largely that according to the prior art, in which a set of points (R_i, G_i, B_i), which depends on the currently selected percentage

35 threshold, in estimated to be the colour of the illumination.

In the method according to the invention, the colour is, however, estimated using a more highly developed algorithm, which sets specific sub-criteria for the points h_i corresponding to the illumination colour $(R_{ill}, G_{ill}, B_{ill})$.

The points h_i, corresponding to the illumination colour $(R_{ill}, G_{ill}, B_{ill})$ are sought by increasing the value i, until the flatness condition set for the colour curve is met essentially for each curve R, G, B. The intensity value R_i, G_i, B_i, which is generally different for each colour component, corresponding to the point h_i (i.e. the percentage proportion corresponding to the point in question) is set as the illumination colour $(R_{ill}, G_{ill}, B_{ill})$.

According to one embodiment, this criterion can also be stated as three sub-criteria. In the first stage of these sub-criteria, it is possible to search each of the colour-component curves R, G, B for such a point h_i common to the curves R, G, B, in which the ratio r_c of the pixel intensity values C_i, C_{i+1} corresponding to the consecutive points h_i, h_{i+1} set in a particular manner, is less than the first threshold value t_i set for it. In other words, the sub-criterion can also be formulated mathematically in such a way that

$$r_C = \frac{C_i}{C_{i+1}} < t_1, \quad in\ which\ C = (R, G, B)$$

As the next sub-criterion stage in the method, an examination can be made as to whether the sum of the ratios r_R, r_G, r_B of the pixel values meeting the first sub-criterion searched in the first stage is less than the second threshold value t_2 set for it. If this condition is not met, a return is made to the first stage to seek a new trio of colour-components meeting the first sub-criterion, all of which will thus be at the same percentage-proportion point h_i, but the intensity values R_i,

G_i, B_i corresponding to this point h_i generally differ from each other. This second sub-criterion can also be formulated mathematically, in such a way that

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$$\frac{R_i}{R_{i+1}} + \frac{G_i}{G_{i+1}} + \frac{B_i}{B_{i+1}} < t_2$$

If the second sub-criterion is not met in the percentage-proportion point h_i, the procedure returns to the first sub-criterion stage. However, if the second sub-criterion too is

10 met using the trio of colour components that have been found (which are found at the point h_i), the procedure moves to the third sub-criterion stage.

In the third sub-criterion stage, an examination is made as to

15 whether the ratio between the maximum pixel-value change and the minimum pixel-value change of the relative speeds of the changes of the pixel values R_i, G_i, B_i found in the first sub-criterion stage is less that the third threshold value t_3 set for it. The condition can also be formulated mathematically,

20 in such a way that

$$\frac{\max\left((C_i - C_{i+1}) \,/\, C_{i+1}\right), \quad in\ which\ C \in R \,\|\, G \,\|\, B\right)}{\min\left((C_i - C_{i+1}) \,/\, (C_{i+1}), \quad in\ which\ C \in R \,\|\, G \,\|\, B\right)} < t_3$$

Columns 3 and 4 of table 9 show examples of listings of the

25 threshold values t_1, t_2, which have been shown experimentally to be valid. The threshold value t_1 can be set in such a way that it is, for example, between 1,04 and 1,125, in which it is increased at intervals that have been shown experimentally to be valid, starting from a base value of 1,04, corresponding

30 to the index value 1. The threshold value t_2 can be set in such a way that it is, for example, between 3,07 and 3,24, in which is it increase at intervals that have been shown experi-mentally to be valid, starting from the value 3,07, corre-

sponding to the index value 1. The threshold value t_3 can be set to be, for example, approximately 4.

The index i, corresponding to the preset percentage-proportion values can be increased, for example 31 times, at intervals shown experimentally to be valid. In table 9, the percentage-proportion set h_1, arranged to be fixed in the cumulative histograms, can be set according to column 2. The index i = 1 corresponds to the greatest intensity value (100 %) set in the histogram from the colour component in question, in which the saturated pixels $G_{(s)}$ and the pixels R, G, B formed at the same image point 15.1 as the saturated pixel $G_{(s)}$ are filtered out when collecting the histograms. The intensity values diminish according to the tabled percentage proportions, i.e., for example, at the point h_{10} 99,6 % of the intensity values set in the histogram which are smaller than or equal in magnitude to the point corresponding to the intensity value in question. Once 31 steps have been taken using the percentage-proportion intervals described, it is finally quite assumable that a colour trio (R_{i11}. G_{i11}, B_{i11}) meeting all the sub-criteria has been found for the colour of the illumination. The finding of such a colour trio will assist in filtering out using the described percentage-proportion division of precisely the saturated pixels $G_{(s)}$ and the image points 15.1 consisting of them, in the histogram-collection stage.

If, for some reason, the situation is such that an index point i meeting the sub-criteria cannot be found, then in that case, the index value i = 32 in question is selected without comparisons as the reference point, i.e. as the brightest flat area and the intensity values of each colour component R, G, B corresponding to the said point h_{32} are selected as the corresponding illumination colour.

The index values $i = 32 - 34$, at the end of Table 9, can be used, for example, in the selection of the gamma value and in checking the correctness of the colours.

5   The value sets of the threshold values t_1, t_2, t_3 are based on experimental observations, made by the applicant, of a good estimation procedure for illumination colours, there being thus no particularly logical explanation of them.

10 Once still a very schematic level, reference is made by way of example particularly to the insets in Figures 4a - 4c, which insets show enlargements of the flat area, from which the common percentage-proportion point h_1 of the histograms R, G, B is sought. It must be understood, that the histograms in the
15 insets are shown with very greatly exaggerated steepness while in other ways too the descriptors may be quite unreal, due to the similarity of their form, but in this case they are only intended to demonstrate the basic principle of the method according to the invention.
20

It can be seen from the histograms R and G that the flat area in them, extending to the extreme right-hand end of the histogram begins, at least compared to histogram B, already quite early. Thus in principle the colour curves R and G would meet
25 the sub-criteria according to the method of the invention already at their extreme right-hand end, or at least closer to the extreme end than in the case of colour curve B.

On the other hand, a percentage-proportion interval $h_1 - h_4$,
30 between which the intensity of the colour B changes quite sharply, at least compared to the colour components R and G, and which is substantially steeper than the still flat area at the extreme right-hand end of such a flat area, can be seen in the histogram B. This rise in the cumulative histogram B can
35 be caused by, for example, the illumination conditions pre-

vailing in the imaging situation, precisely due to which the colour balance of the shot must be corrected, in order to eliminate the effect of the illumination colour.

5   When using the method according to the invention, with reference to the insets of Figures 4a – 4c, the percentage-proportion point h_i meeting the set criteria common to each of the colour components is now found at point h_4, at which a flat area meeting the sub-criteria according to the method of
10 the invention is found from the histogram of the colour component B. The corresponding illumination colour R_{ill}, G_{ill}, B_{ill} is now obtained from the intensity value R_4, G_4, B_4 corresponding to point h_4, which is generally different for each colour component R, G, B.

15

Using the sub-criteria defined above, a surprisingly robust estimate of the illumination colour (R_{ill}, G_{ill}, B_{ill}) can be made. In addition, the reliability of the estimate can be tested using suitable algorithms and the results obtained from
20 them used to decide on the amount of correction required and whether possible readjustment is required.

The amount of correction, in other words, the gain factor G_R, G_G, G_B, is used to adjust the colour balance. The amount of
25 correction is directly related to the set target level R_{tgt}, G_{tgt}, B_{tgt}, to which each estimated illumination colour is converted. The gain factor for each colour R, G, B adjusting the colour balance is obtained using the target colours R_{tgt}, G_{tgt}, B_{tgt} and the illumination colours R_{ill}, G_{ill}, B_{ill} defined in the
30 manner described above corresponding to each colour component R, G, B, in which

$$G_R = R_{tgt} / R_{ill}$$
$$G_G = G_{tgt} / G_{ill}, \text{ and}$$
35
$$G_B = B_{tgt} / B_{ill}.$$

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In full-level correction, the aim is to make the illumination white (tgt = white; the value on the corresponding scaling then being 1000). The colour-component signals are then ampli-
5   fied using the gain factor, in such a way that the colour of the illumination becomes white. The target level can be re-duced as the number of saturated pixels increases, or as the brightness of the original image diminishes. This is because it is not wished to set the gain too high as the brightness of
10 the image diminishes, instead an image taken in the dark should be slightly darker than an image taken in light.

Colour-balance adjustment can be made even more robust by suitably processing the defined gain factors G_R, G_G, G_B. For
15 example, the gain factors G_R, G_G, G_B can be compared to each other and can be required to meet the following conditions for every possible combination:

$$k_{min} G_{Cref} G_C \leq C1_{ref} G_{C1} \leq k_{max} G_{Cref} G_C,$$
$$in\ which \quad C = (R \| G \| B) \quad ja \quad C1 = (R \| G \| B, \quad C1 \notin C)$$
$$k_{min} < 1, \quad k_{max} > 1$$

20

In that case, the correction factor G_R of the red colour C1 = R, will have a specific interval compared to the correction factor G_G of the green colour G. This same applies to all the colours R, G, B relative to the other colours R, G, B. Accord-
25 ing to one embodiment, in these conditions, it is possible to set, for example, k_{min} = 0,66 and k_{max} = 4/3. The value G_{Cref} de-picts the mutual relation of the colour components in standard illumination, relative to which the colour-sensitivity prop-erty of the sensors gives rise to a need for definition. This
30 is because the sensors are typically more sensitive to the green component G than to the red component R and the blue component B. Making an automatic correction will depend on, for example, the sensor manufacturer. If automatic correction

has been made, then the reference value will typically be 1
for all the colour components. If correction has not been
made, then, for example, $G_{Gref} = 1$ can be set for green G, in
which case red can be correspondingly $G_{Rref} = 1,6$ can be set
5   for red R and $G_{Bref} = 2,1$ for blue B.

It should be understood that these numerical values can vary
to some extent, and are thus in no way bound to those stated
here. These values are also based on experimental results,
10 which appeared during the pilot stage of the development of
the algorithm. The gains G_R, G_G, G_B are varied, until the
aforementioned condition is met.

By using these modified gain factors G_R, G_G, G_B, a median value
15 can also be calculated for each colour component R, G, B. If
it is noticed that the difference between the median value of
the selected reference colour component and the median value
of a another colour component is great, the gains are then ad-
justed, so that the difference between them is reduced. For
20 example, the green colour component G can be used as a refer-
ence colour component.

Further, as a final restriction to the gain factor G_R, G_G, G_B,
a condition can be set, that each of them must be between:
25

$$G_{min} \leq G_C \leq G_{max},$$
$$in\ which \quad C = (R, G, B)$$

Here, the value G_{min} i.e. an absolute value, can be set as, for
example, 1 and the value G_{max} as, for example, 16, according to
30 one embodiment, for example, 10.

If the aforesaid restriction is not met in the case of any of
the predefined factors G_R, G_G, G_B, the gain factor or factors

in question are modified and the other factors are correspond-
ingly readjusted in the same relation.

Once the gain factors G_R, G_G, G_B have received their final
5   form, they can next be used to form componentwise mappings for
each colour component R, G, B, which will adjust the colour
balance. In these mappings, the sub-index In refers to the
colour detected by the camera sensor while the sub-index Out
refers to the colour corrected by the gain factor (G_R, G_G, G_B),
10 i.e.

$$R_{Out} = G_R * R_{In},$$
$$G_{Out} = G_G * G_{In}, \text{ and}$$
$$B_{Out} = G_B * B_{In}.$$

15

The componentwise original histograms are shown in the upper
descriptor in Figure 7 while the middle descriptor shows the
componentwise function mappings of them formed from them using
the gain factors defined according to the method of the inven-
20 tion, in which the illumination color is thus taken into ac-
count according to the method of the invention. The lowest
histogram shows componentwise histograms processed according
to the method of the invention, in which so-called offset re-
duction, by means of which the contrast of the dark end is in-
25 creased, are also taken into account.

In the method according to the invention, other operations be-
sides the automatic adjustment CBA, CBC of the colour balance,
described above, can be applied to the image-processing chain
30 system 10, arranged in the camera device itself, or alterna-
tively also in an peripheral device.

Figure 5 shows a first example of these operations, which is
known as so-called pedestal elimination PE, i.e. as an offset
35 correction of the pixel values performed on the raw matrix. As

can be seen from Figure 1 illustrating the image-processing chain, this correction can be performed in the chain 10, on the raw image obtained directly from the sensor.

5   Offset is a minimum value defined from the colour signal, which is obtained if, for instance, a completely dark shot is captured. The sensors of digital camera devices can have different offsets for each colour channel. However, it would be important from the point of view of the operation of adjust-
10   ment of robust colour balance, for the offset to be removed as flawlessly as possible and that for the sensor to be thus linearized. Removal can be arranged to be permanent and sensor-specific, provided the same offsets are systematically increased in the colour-component signals. Adaptive modes can
15   also be used.

Independently of the manner of implementation, in the prior art, in the principle of offset correction of pixel values, the offset values are used to reduce the pixel values. How-
20   ever, in pilot-stage tests, such an operation has been shown to reduce the dynamic area of the signal, because the brightest values are then also reduced.

In the method according to the invention, the offset correc-
25   tion of the pixel values is performed at least partly linearly. According to one embodiment, this can be carried out, for example, by removing the pedestal p by a direct subtraction calculation, if the signal level of the pixels is below the limit value t set for it. If the signal level of the pix-
30   els exceeds the set limit value t, the pedestal p is subtracted, but at the same time the signal is also amplified, so that the maximum signal level does not substantially drop.

Such a pedestal elimination stage PE is particularly advanta-
35   geous, for example, in the case of the method according to the

27

invention, when the illumination colour is estimated and an
attempt is made to essentially eliminate the effect of the
saturated pixel values. In the manner described above, i.e.
performed partly linearly, a saturated pixel will remain satu-
5   rated in the pedestal-elimination PE.

The performance in principle of the pedestal elimination PE
carried out according to the invention can be described using
the following equations, with reference to Figure 5
10

$$y = 0, \text{ when } x < p$$
$$y = x - p, \text{ when } p \leq x < t$$
$$y = x - p + \frac{x - t}{x_{max} - t} p, \text{ when } x \geq t$$
$$\text{in which } \quad p = pedestal \ ja \quad t = threshold \ value$$

The co-ordinate axis analogy is clearly applied in such a way
that y = Out and x = In. In these equations, it can be that,
15   for example x_{max} = 1023, p = 64, and t = x_{max} - (p/2) => 1023 -
(64/2) = 991.

According to yet another embodiment, the image processing
chain 10 can also include so-called edge correction, which is
20   also known in the terminology of those versed in the art as
vignetting elimination VE. Vignetting elimination VE can be
arranged in the image-processing chain 10, for example, after
pedestal elimination PE. One advantage of using vignetting
elimination VE is a reduction in corner darkening in images.
25   The darkening of the corners of an image is generally caused
by the optics and the physical properties of the sensor. The
vignetting phenomenon is characterized by a diminution in the
luminance value of the image, starting from the centre of the
image and proceeding radially towards the corners of the im-
30   age.

A vignetting-elimination algorithm VE according to the inven-
tion can be used to compensate for this drawback, in such a
way that it applies an offset that varies spatially in the im-
age and a vignetting-phenomenon correction factor vf, which
5 can depend on, among other things, the location of the pixels.
The value of the correction factor vf increases as the dis-
tance r of the vignetting phenomenon from the centre point in-
creases.

10 The centre point (r = 0) can be set to be, for example, in the
centre of the image. The correction factor vf can be developed
as a function dependent on sensor-specific parameters and the
distance. The parameters can be defined, for example, using
calibration imaging, in which the sensor is used to image a
15 white surface with standard illumination and from which a
suitable base estimation of the parameters is used to define
parameters such that they can be used to eliminate the vignet-
ting phenomenon. The distance r can be determined in a way
that is, as such, known (for example, Pythagoras's theorem),
20 in which, however, the so-called aspect ratio must be taken
into account as an additional coefficient. Vignetting elimina-
tion is obtained directly, if each pixel value is multiplied
by the factor vf corresponding to the distance r corresponding
to it. In addition, account must also be taken of the fact
25 that the correction factor can also be developed separately
for each colour component R_{vf}, G_{vf}, B_{vf}, due to their different
manners of attenuation. If the colour components are attenu-
ated separately, then it would be good to correct the error
arising from this, so that it will not cause an error in the
30 actual colour-balance adjustment.

It is advantageous to arrange the vignetting elimination algo-
rithm VE in such a way that it comes in the image-processing
chain 10, for example, after the pedestal elimination PE and
35 before the colour-balance estimation stage CBA, because in

that case there will be no possible dark corners in the image
to distort the actual colour-balance adjustment CBC.

Figure 6 shows an example of a further sub-stage that can pos-
5   sibly be attached to the method according to the invention. As
the final sub-stage in an image-processing chain according to
the invention, there can, according to one embodiment, also be
dark-colour correction. In it, values meeting a specific par-
ticular threshold set form them are sought from the cumulative
10   histograms. In the dark-colour correction, the darkest colour
component, determined on the basis of the threshold value, is
stretched by a set amount towards black and the other compo-
nents are also processed in the same proportion. The stretch-
ing takes place by adding an offset of a set magnitude to the
15   colour-conversion functions, as in Figure 6.

According to one embodiment, the dark-end threshold value can
be defined, for example, in such a way that an intensity point
correspond to, for example, 1 % of the number of pixels is
20   sought from the histograms of each of the colour components R,
G, B. After this, the intensity values corresponding to the 1
%-point of each colour component are multiplied by a current
correction coefficient corresponding to each colour component
and the smallest of the modified intensity values thus ob-
25   tained is selected, which modified intensity value is further
multiplied by 0,7 and is then selected as the magnitude of the
correction.

The magnitude of the correction defined and selected above is
30   next divided by the current correction factors G_R, G_G, G_B, as a
result of which division offset values OffsetR, OffsetG, Off-
setB are obtained for each colour component. It should be
noted that the offset values do not effect the colour, but
only stretch it to become darker. In order that the colour-
35   balance adjustment target level can be made to remain as it

was originally intended, newly adjusted correction factors G_R', G_G', G_B' must still be defined. If there are no dark points in the image, the contract can be (slightly) increased.

The lowest histogram in Figure 7 shows an example depicting a histogram obtained by the correction of the colour of the dark pixels, in which, when correcting the colour of the dark pixels, an offset defined in the aforementioned manner is added to the conversion functions, resulting in the readjustment of the amplification of the conversion functions. As a result of the correction of the dark end, the conversion functions receive the following form

$$R_{out} = G_R' * (R_{In} - OffsetR),$$
$$G_{out} = G_G' * (G_{In} - OffsetG), \text{ and}$$
$$B_{out} = G_B' * (B_{In} - OffsetB).$$

This process then has the result that the points brighter than the definition point are converted to be bright and the points darker than it are made darker. The effect of the change on the histograms is illustrated in the lowest descriptor of Figure 7, which also shows the final componentwise histograms obtained as a result of the image-processing chain 10 according to the invention. The mappings functions formed from the colour components are shown in the middle In/Out descriptor.

Linear conversion functions can be used in the method according to the invention. Non-linearities can also be added and typically are added, if the algorithm used is further combined with possible gamma correction, as an additional embodiment.

According to one embodiment, gamma correction GC can be implemented in such a way that first of all the type of image is defined. According to one example of the embodiment, this can be done by searching for the 25 %, 50 %, and 80 %-points on

31

the X-axis of the cumulative histograms, in which, at the 25 %-point, for example, 25 % of the pixels forming the image have an intensity value that is darker than, or equal to that of the point. Criteria for the intensity values, on the basis of which a decision can be made as to whether the shot currently being processed is normal, backlight, or low-contrast, are set to correspond to the percentage proportions 25, 50, and 80. After definition, a smaller gamma-value is selected in proportion to how much the image should be brightened. In the CEI/IEC organization (Commission Internationale de l'Eclairage (Vienna) / (International Electrochemical Commission (Geneva)) has selected the gamma level $0,45 = 1/2,2$, in Figure 8, for SRGB (standard RGB) images. In the method according to the invention, the gamma values can vary, for example, from 0,20 to 0,60. On a general, very approximate level, it can be stated that, in the gamma correction, the colour balance is adjusted in the final stage of the adjustment chain 10 by an increase in the order of power in which suitable intensity areas involution is made for the intensity values in which order of power corresponds to the gamma value. A direct power-order increase is not carried out in the initial areas of the curve, to prevent the change in the dark area being too rapid (steep).

The sub-stages of the colour-balance adjustment method according to the invention can, according to one embodiment, be summarized as follows.

1.   Eliminate the pedestal PE,
2.   Elimination vignetting VE,
3.   Collect a histogram by filtering out the saturated pixel values $G_{(s)}$ and also the image points 15.1 corresponding to them,
4.   Define an estimate for the illumination colours R_{ill}, G_{ill}, B_{ill} from the cumulative histograms, using bound-

ary conditions t_1, t_2, t_3 according to the method of the invention,

5.   Define using the estimate of the illumination colour, necessary colour-conversion mapping functions and using them adjust the developed boundary conditions and limitations,

6.   Adjust the darkest value of the colour components R, G, B,

7.   Use the addition and histogram data when deciding on the visual optimal value for the gamma correction.

Stage 3, 4, 5, and 6 form the core components of the method according to the invention. It should be noted that, depending on the implementations, these stages can be rearranged or combined in several different ways.

It must be understood that the above description and the related figures are only intended to illustrate the present invention. The invention is thus in no way restricted to only the embodiments disclosed or stated in the Claims, but many different variations and adaptations of the invention, which are possible within the scope on the inventive idea defined in the accompanying Claims, will be obvious to one versed in the art.